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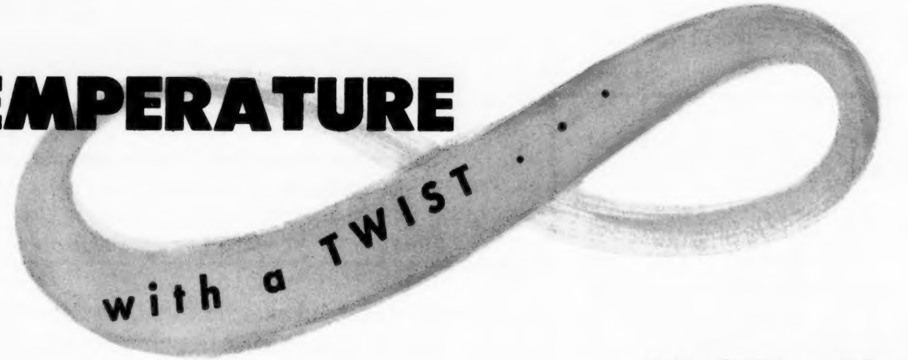
TEMPERATURE with a TWIST . . .



by LEO S. PACKER

Special Vortex Tube Measures Free-Air Temperature From An Airplane

FEW devices in technological history have had the distinction of being the subject both of an article in *Amazing Stories* and of a doctoral dissertation, of being offered for sale commercially while being studied in a profound scientific manner, of presenting a puzzle to trained scientists and yet being a fad for gadgeteers in basement workshops. Such, however, has been the history of the Ranque-Hilsch, or vortex, tube in the few years it has been known in this country.

The baffling thing about the conventional vortex tube is the contrast between its mechanical simplicity and operational complexity. The special whirling flow pattern produces a separation of the airstream into hot air and cold air. This separation can be used, for example, to obtain outgoing airstreams at high and low temperatures, or in C.A.L.'s temperature-measuring application, to produce a stable region of cold air in which a thermal sensing element is immersed. Although any amateur mechanic can build a vortex tube, fluid dynamicists are still unable to describe adequately how it operates. Three or four competing theories are still being disputed. These rather sharp differences in viewpoint have been prominent throughout the history of the device.

In 1933, G. J. Ranque, a French mining engineer working on centrifugal air cleaners, observed an unexpected temperature difference in a vortex flow. He was able to split the incoming air into separate cold and hot airstreams. His disclosure at a scientific meeting was received with skepticism by the leading fluid dynamicists of the day. It was implied that Ranque did not appreciate the difference between static and stagnation temperature. Unfortunately, he was unable to defend his work in professional, fluid-flow terminology. Apparently his critics did not consider it worthwhile to test his claim with a simple experiment. He eventually obtained a patent, formed a company to exploit the device, and then dropped into obscurity. Nothing further is known about his activities or those of his company.

Shortly after World War II, a team of U. S. scientists visiting the University of Erlangen in Germany happened to meet R. Hilsch, a physics professor who had performed the first systematic experimental investigation of vortex tube refrigeration. The Americans brought back vortex tubes and arranged for Hilsch to publish his results in this country. Considerable interest was aroused by Hilsch's article, which appeared in February 1947 in the *Review of Scientific Instruments.* Since then, numerous attempts have been made to explain the behavior of the tube, to measure its performance and to adapt it to a variety of applications. There now exist almost a dozen patents involving applications of the Ranque-Hilsch tube.

C.A.L.'s VORTEX TUBE STUDY

Early in 1951, the U. S. Navy Bureau of Aeronautics sponsored at C.A.L. a broad study of the vortex tube in an effort to adapt its unique properties to the measurement of free-air temperature from an airplane. The idea underlying the C.A.L. study was suggested in 1950 by B. Vonnegut of the General Electric Company. A sample of air, when captured for temperature measurement, is unavoidably heated. Vonnegut demonstrated that part of this air can be cooled down again by processing through a vortex tube. If this tube is artfully designed, the heating and cooling effects will

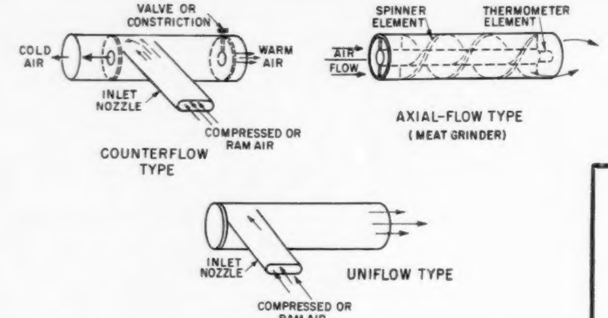


FIG. 1 BASIC TYPES OF VORTEX TUBES

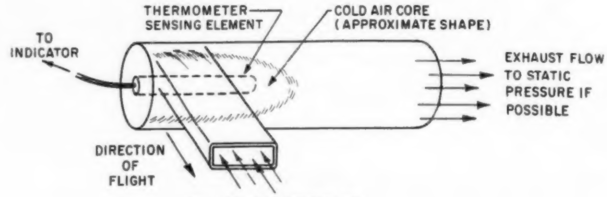


FIG. 2 SKETCH OF BASIC UNIFLOW VORTEX THERMOMETER
(AIRFOIL-SHAPED HOUSING NOT SHOWN)

cancel one another; hence the correct measurement of temperature can be obtained within the refrigerated sample.

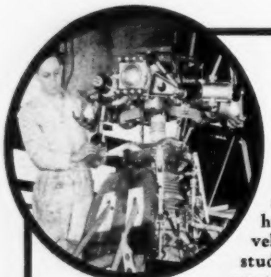
It is well known that one cannot simply stick a thermometer out the window of a moving airplane and expect to obtain a valid outside temperature reading. The dynamic compression of the outside air impacting against the thermometer, as well as the heat generated in the boundary layer around the thermometer, causes the thermometer to read a temperature which is too high. The error is largely a function of the Mach number of flight and the free-air or ambient temperature. Radiation and conduction heat-transfer coefficients and the geometry of the probe also play significant roles in the temperature error which may be as great as 40°C even for subsonic flight at sea level. As airplanes fly faster and faster, the measurement of free-air temperature becomes more and more difficult. At the same time, the need for determining free-air temperature in flight has been emphasized in the fields of meteorology, aircraft operation and ballistics. Now if a temperature-compensating vortex tube is properly designed, the conventional thermometer element in the "cool" air region in the vortex would read accurate free-air temperature. Vonnegut demonstrated the feasibility of the idea by actually flying a sample vortex tube over a limited speed range.

The problem is to obtain the reading of a thermometer suspended motionless in the air just as an airplane flies past. The thermal sensing element immersed in the cold air region of the vortex tube must read the same as would such a suspended thermometer and must do so regardless of changes in flight conditions. Any suggestion for directly eliminating the aerodynamic heating error by reeling out an ordinary thermometer from an airplane so as to have a "stationary" thermometer is obviously grotesque. If such a solution were possible, there would be little need for vortex thermometers.

The requirement for cancellation of the dynamic heating is quite demanding; the cooling produced in the vortex tube must match and cancel the aerodynamic heating caused by the relative motion of the thermometer and the surrounding air mass. The matching must hold over a wide range of the pertinent flight parameters and must not be invalidated by changes in extraneous parameters.

Figure 1 shows diagrammatically the three basic types of vortex tubes. The best known configuration is the counterflow type investigated by Hilsch. It produces a current of cold air and a current of hot air. The axial-flow tube was investigated by the Naval Research Laboratory. The uniflow tube, simplest of all, is the type developed by C.A.L.

Figure 2 illustrates the manner in which the uniflow vortex tube is applied to free-air temperature measurement. Suppose that the inlet nozzle of the tube is



THE COVER

The photo insert at left, also reproduced on the cover page, shows a C.A.L. employe working at the Laboratory on the complex helicopter rotor instrumentation developed for stability and control studies in the Flight Research Department. The helicopter has always been difficult to fly. Tail surfaces are stabilizing forces in the fixed-wing aircraft. They are almost ineffectual in stabilizing the rotary-wing aircraft when it hovers or performs vertical maneuvers. Also, pilot fatigue is greater in rotary-wing than in fixed-wing aircraft because a higher degree of attention is required in flight.

Flight test evaluation of important aerodynamic stability values is a current program. Data obtained will offer researchers needed experimental values for comparison with previous theoretical calculations of the helicopter's complex stability and control characteristics. However, measurements must be taken on the rotor system whirling at high speed and subject to a variety of large, oscillating forces, and at the same time they must be recorded in a non-rotating system. Specialized instrumentation has been devised by C.A.L. for the U. S. Navy.

The Aero-Mechanics Department also has been evaluating new means of stabilization as well as theoretically evaluating existing systems to improve stability and control characteristics. The Reeves Electronic Analogue Computer has been used to simulate helicopter configurations employing various stabilizing devices.

aligned in the direction of motion of the airplane so that air is rammed into the nozzle. By entering the vortex tube tangentially, the air is forced into a vortex-like motion adjacent to the solid disk forming the closed end of the tube. A central core of cold air exists in this region. As new cold air is generated by the steady flow into the tube, the cold air mixes with warmed air at the periphery of the cold core. Thus the cold core is being constantly replenished. If the Mach number of flight changes, the temperature in the cold core will change quite rapidly and adjust to a new steady state. The temperature of the air issuing from the open end of the tube is not appreciably different from that of the supply air. The cold-air core can be used to provide a stable, reproducible temperature reading which can be adjusted to conform to the free-air temperature of simulated flight over a wide range of Mach numbers and temperatures. A properly proportioned thermal sensing element indicated free-air temperature for all realistic combinations of temperature and Mach number (subsonic only, thus far); changes in humidity and altitude do not upset the correctness of the indication. The desired accuracy, however, depends on proper tube geometry and on compatibility of the sensing element. Hence, much of the work in the first phase was concerned with determining the geometry for the desired cooling characteristic.

FIGURE 3 — Early thermometer installations on an F-80A airplane to check validity of flight simulation techniques. C.A.L. thermometer encircled.

Although no good theory exists to describe the roles played by the various parameters and their interactions, the following fairly obvious variables enter into the performance of a vortex tube: tube diameter, tube length, shape and area of inlet nozzle, number of inlet nozzles, diameter of sensing element, axial location of sensing element, pressure ratio causing the internal flow (related to Mach number of flight), any humidity, static pressure and free-air temperature of the ambient air. Since the vortex tube is to be attached to an airplane (see Figure 3), the list must also include the aerodynamic effect of different thermometer-housing designs, the interaction between airflow through the vortex tube and airflow around the tube, airplane angle of attack and yaw changes, and pressure and flow direction changes at the mounting location. Moreover, the final thermometer should be small, rugged, simple, protected against icing and easily mountable. Fast response and temperature sensitivity adequate for existing indicating systems are other desired attributes. As an interim requirement, ± 1 °C was established as an accuracy goal.

With such an impressive list of variables and requirements, some dependent on others, a step-by-step experimental program was laid out. There was little hope that an analytical approach would make much headway in the solution of the development problems.

PRELIMINARY DESIGN

The first and most obvious requirement was a combination of vortex tube and sensing element which would give the desired cooling characteristic. To have used, actual flight testing or wind tunnel testing to evaluate preliminary design changes would have been intolerably slow and expensive. Therefore, apparatus was constructed to test thermometer performance in the laboratory under simulated flight conditions. In the simulation phase, it was assumed that the internal flow alone approximately determines the reading of the axially-mounted thermal-sensing element. Therefore a closed air jet, smoothly accelerated from a stagnation tank, was used to operate the vortex tube. Figure 4 is a schematic representation of the flight simulation equipment which is capable of controlling the temperature, humidity and pressure of the supply air. Later work in wind tunnels confirmed that the simulation method provided a valuable prediction of performance, even though the effect of external flow around the tube could not be duplicated conveniently in the laboratory. This phase of the program yielded a vortex tube geometry which provided a satisfactory reading of free-air temperature by means of a special resistance thermal element. The thermometer was tested up to high subsonic Mach numbers and over a wide range of temperatures.

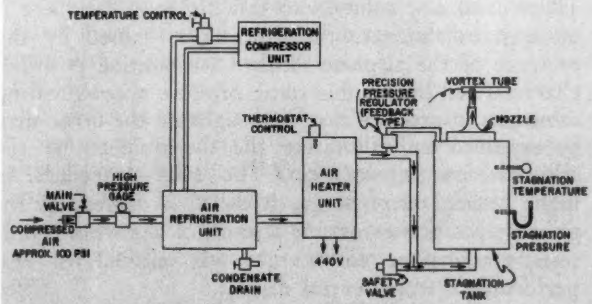


FIG. 4 SCHEMATIC DIAGRAM OF FLIGHT SIMULATION APPARATUS

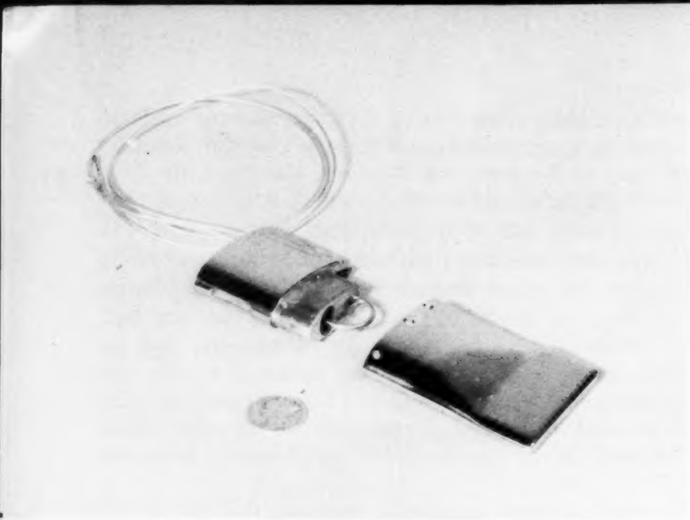


FIGURE 5 — Vortex tube showing exhaust chamber shell and main body with wires connecting to temperature indicator. Coin shows relative size of the device.

DEVELOPMENT OF A MINIATURE THERMOMETER

To determine how small the thermometer could be made, successively smaller thermometers were tested in the laboratory. The most difficult problem in this work was the development of a tiny resistance element — small enough to be used in a 3/8-inch diameter vortex tube, yet possessing the electrical characteristics required to actuate standard indicators — and rugged enough to withstand the severe buffeting in the core of the vortex tube. The final winding was enclosed in a hypodermic tube of 0.049-inch outside diameter. The vortex tube (Figure 5), measuring 1.6 x 0.4 x 3.4 inches and weighing 1½ ounces, performed as well as any of the larger prototypes.

Attention was focused on the disturbing effects of air flowing over the airfoil-shaped vortex tube housing. These aerodynamic disturbances may change the performance as observed in the laboratory simulation tests, in which there is no external flow and the internal flow discharges to still air at atmospheric pressure. Hence, they are best studied in the wind tunnel. These tests are intimately related to the problem of choosing a mounting location for the vortex tube on an airplane. The problem is to mount the tube at a location where true static pressure exists; otherwise the thermometer will record the "local" free-air temperature (the free-air temperature at the vortex tube location) rather than the temperature of the undisturbed and remote air mass. There is no easy solution to this problem, for there is no way to eliminate the disturbance caused by the presence of the airplane. Either a mounting position, characterized by a stable static pressure approximating atmospheric pressure may be sought or the error may be removed by calibrating the thermometer at the selected mounting location. The latter procedure, in flight testing terminology, is called a correction for pressure-position error. As a result of the wind tunnel tests, a miniature vortex tube was selected for best performance from several designs.

FLIGHT TESTS

Since no flight simulation method exactly duplicates all the conditions of actual flight, the miniature vortex thermometer is being flight tested. It is mounted at various positions on the nose of an F2H-2 jet airplane. Very careful airspeed and altitude calibrations will be needed and a static-pressure survey will be made at various locations on the airplane. For comparison with vortex thermometer indications, accurate measurements of reference free-air temperature will be made from independent sources. The results of this program, currently underway, should establish the worth of the miniature vortex thermometer.

In effect the C.A.L. viewpoint can be expressed quite briefly. In the absence of a comprehensive theory, only a practical flight-simulation procedure was worthwhile. By use of a simplified theory, a simulation technique was devised. Proper interpretation of simulation data, together with systematic variation of parameters, showed how to control performance variables. The validity of the design was checked in wind tunnel tests; the most promising design was then subjected to the ultimate and most meaningful test of performance, a carefully planned and controlled flight program. The next step, now in progress, is to make pre-manufacturing studies in anticipation of quantity production.

The future trend of vortex tube work at C.A.L. will include more icing and internal flow studies, transonic and supersonic tests to extend the operating range of the vortex thermometer, and exploitation of a related device, the vortex whistle. Until recently, the piercing sound emitted by the vortex tube had been considered merely a necessary nuisance — a sure-fire way to lose friends and alienate people. Sponsored by the U. S. Air Force this additional project has so far revealed that the fundamental frequency of the sound produced by the tube is uniquely related to the true airspeed of flight. This interesting fact may eventually result in a novel aircraft instrument in which a single vortex tube will measure both true airspeed and free-air temperature without any computation. From these two measurements, the Mach number, if desired, may be computed quite simply.

Though we cannot predict exactly what sort of adult life it will have, the vortex tube as a subject of technical study has come of age. Last spring the first symposium on vortex instrumentation attracted representatives from a wide range of companies and government agencies. Ten years ago, the vortex tube was unknown in this country. Apparently it is here to stay.

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ELECTRONICS TOO HOT TO WORK?

C.A.L. Studies Show Electronic Reliability Is Closely Related to Adequate Cooling Methods

by JAMES P. WELSH

Our civilization has become vitally dependent on electronic devices and, consequently, the reliability of electronic "black boxes" is an increasing concern to designers and users. An airborne instrument landing receiver must be more reliable than an ordinary domestic radio receiver. If the Instrument Landing System (ILS) should fail during a landing in bad weather, a fatal crash could result. However, reliability does not necessarily require long life; it is associated with the design life of the device. The expendable electronic equipment in a missile must have performance fantastically dependable during the minute or two it is turned on in service.

The design of equipment which exhibits the required degree of reliability is sometimes difficult. It has been found that the many techniques of careful engineering which lead to reliability are interrelated and not readily isolated. As in a chain, most electronic circuits in equipment are linked together. Should any single part or connection become defective the entire equipment will fail. To strengthen the reliability "chain" it is necessary to scrutinize and improve both the individual links and their interactions wherever connected. This reform includes good design and construction, quality of the parts, proper maintenance and use of the equipment and control of its environmental conditions. Associated with environment and design is one of the more difficult reliability problems, namely, that of cooling the parts which must not overheat. This problem is made particularly difficult by the constant pressure to make each succeeding revision of a given design smaller than the last.

MINIATURIZATION

Satisfactory reliability can be designed into electronic equipment. However, operational requirements, especially those of the armed services, are becoming more stringent. New equipment must be small, light, rugged and capable of withstanding high temperatures. One current solution to these requirements has been to "scale down" the equipment by a process called miniaturization. Subminiaturized devices have the obvious advantages of ruggedness, compactness and light weight. However, they are frequently expensive, difficult to repair and subject to overheating. Their performance must be equivalent to that of their larger counterparts and the electrical power dissipation is usually the same. Unfortunately, therefore, the watt has not been miniaturized, and the unwanted heat becomes concentrated in a smaller volume in the miniaturized unit. Consequently the temperatures of the parts rise considerably. Since most electronic parts cannot withstand extremely high temperature, such high heat concentrations can easily lead to unreliability and failures.

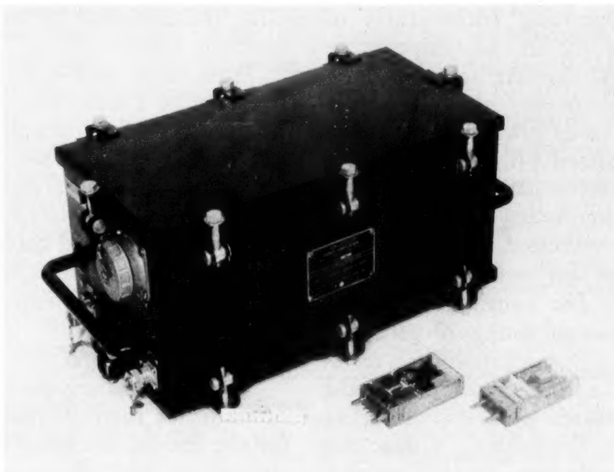

FIGURE 1 — Dimensions of subminiaturized units (without power supply) compared with those of larger miniaturized unit (with power supply).

The reliability aspects of miniaturization and electronic equipment cooling are being investigated at C.A.L. During a four-year program several subminiature subassemblies (see Figure 1) were developed for the U. S. Navy Bureau of Ships. These devices were designed for continuous operation at environmental temperatures as high as 300°F. At the time they were built these units were among the few American electronic devices best able to withstand high temperature operation. Special high temperature parts and materials were utilized and particular attention was given to the removal of internally developed heat. Despite reduction in size, the miniaturized units exhibited slightly better electrical performance than standard-size devices.

COOLING

Reliability is closely related to the adequacy of cooling. Significant numbers of standard military electronic devices have failed in service because of overheating. It appears that unless adequate heat removal is provided in future military equipment, most of which will be miniaturized, resultant reliability will be unsatisfactory.

Design methods for electronic equipment with desirable thermal characteristics are not commonly known, and most organizations which have produced successful designs have achieved their goals by methods devoted exclusively to a specific equipment design. Not enough engineering groups have been assigned the time

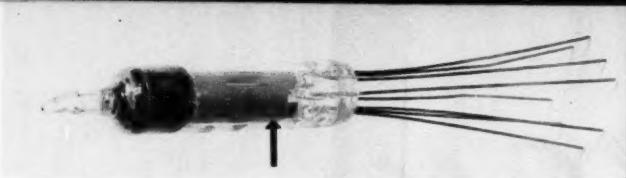

FIGURE 2 — Type 5902 Thermatron. Arrow indicates fine wire thermocouple on plate.

FIGURE 3 — Shadowgraph of subminiature tube immersed in alcohol. Note radiation halo surrounding area of the plate and convection currents of strongly heated liquid rising upward to the surface.

or money to ferret out the underlying principles governing details of heat flow in electronic parts and assemblies. The United States Navy determined that a series of electronic cooling design manuals should be published to aid engineers in the design of reliable military electronic equipment. In 1952 C.A.L. was awarded a contract to prepare them. This program continues today.

HOW HOT IS TOO HOT?

One difficulty facing the electronic engineer in the thermal design of equipment is the determination of the maximum safe operating temperatures of parts. A few thermal "bench marks" which have been empirically established do allow rough predictions of the life of vacuum tubes under known conditions of operation. However, ideal thermal configurations are seldom achieved in electronic devices, especially when a wide range of environmental conditions must be met. The recommended maximum operating temperatures of parts are usually limited by the size of temperature-caused variations in electrical characteristics and their effect on electronic performance, the degree of reliability and life desired and, primarily, the temperatures the parts can withstand without failure. But the "failure" of most electronic parts is not simple. Certain parts such as vacuum tubes do not fail immediately when they are overheated but instead deteriorate rather erratically so that accurate life prediction is no longer possible. The situation is further complicated by optimistic thermal ratings of parts and equipment. These ratings usually are expressed in terms of ambient temperature — i.e., the temperature of the medium surrounding an isolated part. However, an ambient rating alone is not satisfactory; it does not include the radiation and conduction interactions with other hot spots which may be nearby. These effects can be significant when closely spaced parts have a high heat concentration and, consequently, overheating may occur even though the ambient rating is not exceeded.

ELECTRON TUBES

Tubes are usually the primary heat sources in electronic equipment. Analyses of failures have shown that many of the shortcomings which vacuum tubes develop, such as grid emission, loss of emission, gas formation, glass failures and internal shorts are directly related to the thermal history of the tubes.

The internal thermal characteristics of electronic tubes were studied for a better understanding of tube temperature limitations and to determine the best methods of removing internally developed heat. A series of special instrumented tubes with small thermocouples on the appropriate elements were built for this purpose. It was soon apparent that plate temperature was a good index of the thermal condition of a tube. Cooling techniques, such as liquid cooling and conduction into tight fitting tube shields, can be more readily evaluated because of this finding. Glass bulb temperatures are not of direct importance as long as peak glass temperatures in excess of 350° F are not encountered. Heretofore, most thermal analyses had been predicated on glass bulb temperature, a quantity which is sometimes difficult to measure, and is at best an indirect result rather than a good measure of the true thermal condition of a tube. Under certain conditions of operation a poorly-cooled tube will exhibit 10° to 20°F lower glass temperature than a well-cooled tube. This result is due to the slightly shorter wave-length of the dominant radiation from the hotter plate and the correspondingly increased transmission through the glass. Thus, the glass may be hotter when the internal elements are cooler.

From these studies it was found that the degree of cooling of a tube could be specifically determined as inadequate cooling, marginal cooling, proper cooling and overcooling. This determination is dependent upon the ratio of net internal and external thermal resistances with respect to the glass bulb. Since the gross internal resistances for typical cooling conditions have already been established, the designer now only needs to control the total external thermal resistance to control his degree of cooling.

THE THERMATRON

Plate temperature data, which provide a true indication of the thermal conditions of tubes, are desirable for the reasons discussed above. With the special instrumented tube, the thermocouple circuits attached to plates are several hundred volts above ground. The ideal tube for plate temperature determination is a simple diode. Several experimental filament types were tested and it was shown that for the purpose of these tests the plate could be heated just as well by radiation as by electron current bombardment, and that this is true for any given power level. This finding led to the development of a special diode with a large filament capable of operating at the gross dissipation of a given tube structure. The plate is heated by radiation from the filament. The plate temperature is monitored by a thermocouple and, since plate voltage is not required, the indicating instruments can be operated at ground potential. The diode has been nicknamed the "Thermatron" (see Figure 2). A series of these diodes which thermally simulate octal, miniature and subminiature tubes have been developed. They can be inserted into almost any given tube socket in equipment to determine the degree of cooling.

LIQUID COOLING

When liquid cooled vacuum tubes are photographed using a point source of light, shadows of the heat flow

patterns are sometimes visible. Figure 3 shows the radiation and convection patterns obtained with a subminature tube immersed in alcohol. Note the radiation from the plate. Such observations are an aid in studying the merits of coolants.

When a thermatron was immersed in water at room temperature, the plate temperature increased while the bulb temperature decreased by as much as 150°F from that obtained in free air. We believe that the phenomenon was due to a highly reflective surface formed at the interface between the glass and the water which reflected radiant energy back into the tube. The effect was caused primarily by the difference in the refractive indices of liquid and glass and this was verified by supplementary experiments with a liquid having an index of refraction more nearly equal to that of glass. Thus we know that the index of refraction is another characteristic which must be considered in the selection of coolants.

TRANSISTORS

Transistors hold considerable promise in supplementing vacuum tubes. They do not have heaters or filaments to burn out. Some have exhibited significantly longer life than vacuum tubes. However, their potential reliability remains to be achieved. Good transistor action requires a small but closely controlled population of foreign atoms in the active materials, usually germanium or silicon. However, if minute quantities of moisture or additional "impurities" are permitted to enter the device, operation may be modified or cease altogether. High temperatures assist the migration of these unwanted impurities. Many early transistors enclosed in plastic cases were poisoned by foreign materials which leaked in; manufacturers are now emphasizing improved sealing techniques similar to those for vacuum tubes.

The power handling capabilities of high power transistors are limited by the heat which can be conducted through the semiconducting material. Very effective heat transfer means must be utilized since some of the new transistors control currents as great as 30 amperes. Liquid cooling has proved to be excellent for power transistors. Although transistors today are unstable with temperature and for this reason may not always meet military requirements, the development of improved transistors is continuing and significant advances in reliability and performance are anticipated.

THE BASIS OF RELIABILITY

Conservatism must be the aim of every design for reliable equipment. Electronic part ratings are usually published as maximum values and there is an unfortunate tradition of economy in electronic design whereby some parts often are operated near or past these levels. If the resulting device is to be truly dependable, an adequate margin of safety must always be left in the design of an electronic assembly. Reliability results from the application of good judgment and conservative designs using the kind of information provided by experimental programs such as the one described here. Prewar radios which faithfully operated for extended periods without failure were good examples of reliable design, but performance requirements and available space and power are all much tighter today. Acceptable reliability can be achieved only if electronic, thermal and mechanical designs are all well executed and if parts are properly utilized in a conservative fashion.

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*Above reports must be distributed through Bureau of Ships, U. S. Navy. All requests should be addressed to Editor, Research Trends, C.A.L.

About the Authors...

LEO S. PACKER has been associated with C.A.L.'s vortex thermometer program for four years. He was appointed project engineer on the instrument program in 1951 when the Laboratory first began research and development in the field. He is now head of the Instrumentation Section of the Physics Department.

Mr. Packer received a Bachelor of Mechanical Engineering degree from the College of the City of New York in June, 1941. His first professional employment was in the model shop and development department of the B. G. Corporation, producers of aircraft ignition systems. His duties included development of new products, production studies, machine design and field testing of experimental products.

He entered the U. S. Army as a Lieutenant in the Corps of Engineers in 1943, having held a reserve commission since graduation. After discharge in 1947 with the rank of Captain he was employed as a development engineer in the Gyroscopics Section of the Research and Development Division of the Arma Corporation. During a leave of absence, he obtained an M.S. degree in Mechanical Engineering from Harvard University. He joined C.A.L.'s Physics Department as a research mechanical engineer in 1950.

He is a licensed professional engineer, member of the American Society of Mechanical Engineers, Tau Beta Pi and Sigma Xi. He held a C.A.L. fellowship at Cornell University in 1953-54 and is now completing a thesis for the Ph.D. degree in Engineering Mechanics.

JAMES P. WELSH is a leading Civil Defense officer in New York State and consultant to the Federal Civil Defense Administration. He serves as Technical Advisor and Alternate Radio Officer of the New York State CD Commission, alternate C.A.L. delegate to the Radio Technical Commission for Aeronautics and member of the Technical Committee of the National CD Alliance.

Mr. Welsh attended Carnegie Institute of Technology from 1934 to 1938, with major studies in electrical engineering. He worked for the Colonial Radio Corporation as a junior engineer, the National Aniline Chemical Corporation and the Lummus Company as a design engineer. In 1943 he joined Curtiss-Wright Research Laboratory as an electrical engineer in the former Armament Division. He continued with the Laboratory when it became affiliated with Cornell University in 1946 as the Cornell Aeronautical Laboratory. He is now head of the Electronics Section of the Industrial Division.

He has been engaged in research and development work related to most types of airborne and shipboard electronic equipment used by the armed services. He has been project engineer of C.A.L.'s miniaturization project and for the past five years has been engaged in two research projects on heat transfer in electronic equipment.

He is a member of the American Institute of Electrical Engineers, the Aero Club of Buffalo, Sigma Xi, and the Institute of Radio Engineers.

Recent
C. A. L. PUBLICATIONS

Requests for copies of the following unclassified reports should be directed to the Editor

"ARTIFICIAL STABILITY INSTALLATION IN C-45 AIRPLANE," Kidd, E. A., Gould, A.; C.A.L. Report TB-754-F-2; 122 pages; July, 1953.

This report describes the function, operating procedure and maintenance of the mechanical, hydraulic and electronic installations in the C-45 airplane which provide artificial stability to make all the natural modes of the airplane's motion essentially non-oscillatory and convergent.

"A STUDY OF THE RAIN EROSION OF PLASTICS AND METALS," Lapp, R. R., Stutzman, R. H., Wahl, N. E.; WADC TR 53-185, Part 2, PC-743-M-30; 156 pages; November, 1954.

This report is a compilation of test data obtained, mostly at 500 mph and one-inch per hour rainfall, on various metallic and non-metallic aircraft materials, using the rotating arm erosion apparatus.

"CELLULAR SLOT BURNER FLAMES," Markstein, G. H., Schwartz, D.; paper presented at Gas Dynamics Symposium, Northwestern University, Evanston, Ill.; 42 pages; August, 1954.

Description is made of a slot burner method developed for investigating cellular flame structure.

"DEVELOPMENT OF LEAN-ALLOY CHROMIUM-NICKEL STAINLESS STEELS FOR HIGH TEMPERATURES USE, FINAL REPORT," Salvaggi, J., Guarnieri, G. J., C.A.L. Report KA-797-M-14; 80 pages; December, 1954.

Investigation concerned with the development of modified chromium-nickel stainless steel compositions with improved high-temperature strength is detailed in this report.

"FINAL REPORT ON STUDY OF THE EARTH'S ELECTRICAL FIELD," Garber, D. H.; C.A.L. Report RA-764-P-15; 159 pages; June, 1955.

The object of this program, outlined in the report, was to correlate measurements of the earth's electric field and positive and negative atmospheric electrical conductivity with other meteorological parameters.

"HELICOPTER HANDLING QUALITIES INVESTIGATION, PHASE II, ANALYSIS OF HELICOPTER STABILIZATION AND CONTROL PROBLEMS, PART B, PHYSICAL DISCUSSION OF HELICOPTER HANDLING QUALITIES," Donovan, A. F.; C.A.L. Report TB-707-S-2; 116 pages; June, 1955.

This report is devoted primarily to a physical description of the stability and control characteristics of the helicopter unmodified by stabilizing devices.

"HELICOPTER HANDLING QUALITIES INVESTIGATION, PHASE II, ANALYSIS OF HELICOPTER STABILIZATION AND CONTROL PROBLEMS, PART C," Daughaday, H., DuWaldt, F. A.; C.A.L. Report TB-707-S-2; 181 pages; June, 1955.

Description of various existing stabilizing devices and a physical explanation of how each one affects helicopter flying qualities is made in this report.

"ON A FUNCTION ASSOCIATED WITH MODIFIED BESSEL FUNCTIONS," Goodman, T. R.; C.A.L. Report 72; 8 pages; June, 1955.

This report evaluates a new function associated with modified Bessel functions in connection with the problem of finding the trajectory of a particle in the neighborhood of a thin cambered airfoil.

"ON THE REFLECTION OF SHOCK WAVES FROM AN OPEN END OF A DUCT," Rudinger, G.; reprinted from the Journal of Applied Physics; 13 pages; August, 1955.

The readjustment of the mean exit pressure to its steady-flow equilibrium level, following the arrival of a shock wave at an open end of a duct has been investigated. Possible significance of the lag in the establishment of steady-flow boundary conditions in practical applications is discussed.

"ON THE STABILITY OF A PLANE FLAME FRONT IN OSCILLATING FLOW," Markstein, G. H., Squire, W.; reprinted from the Journal of the Acoustical Society of America; 9 pages; May, 1955.

The first step in a proposed dominant mechanism of vibratory flame movement is proposed. Results in qualitative agreement with experimental observations are derived.

"PRECISION RANGING WITH A PULSED OPTICAL RADAR," Geller, L., Lawton, J.; paper presented before National Conference on Aeronautical Electronics, IRE, Dayton, O.; 8 pages; May, 1955.

Pulsed ranging system performance in the presence of additive white noise is analyzed. A method of specifying optimum time discriminator characteristics for precision ranging measurement with a known pulse shape is developed.

"THE CREEP-RUPTURE PROPERTIES OF AIRCRAFT SHEET ALLOYS SUBJECTED TO INTERMITTENT LOAD AND TEMPERATURE," Guarnieri, G. J.; authorized reprint from the copyrighted Symposium on Effect of Cyclic Heating and Stressing on Metals at Elevated Temperature — Special Technical Publication No. 165; 146 pages; 1954.

The high-temperature creep-rupture properties of six sheet alloys having application to aircraft design were investigated under conditions of intermittent load and temperature for comparison with their corresponding constant-temperature constant-load behavior.